

Appendix A

Tables

A.1 Bases and Transforms of Set Functions

	Transform	Basis
Möbius	$m^\xi(S) = \sum_{T \subseteq S} (-1)^{ S \setminus T } \xi(T)$	$u_T(S) = \begin{cases} 1, & \text{if } S \supseteq T \\ 0, & \text{otherwise} \end{cases}$
Co-Möbius (commonality)	$\check{m}^\xi(S) = \sum_{T \supseteq X \setminus S} (-1)^{n- T } \xi(T)$	$\check{u}_T(S) = \begin{cases} (-1)^{ T }, & \text{if } S \cap T = \emptyset \\ 0, & \text{otherwise} \end{cases}$
Conjugate unanimity games	$\bar{U}^\xi(S) = (-1)^{ S +1} \sum_{T \supseteq X \setminus S} (-1)^{n- T } \xi(T)$	$\bar{u}_T(S) = \begin{cases} 1, & \text{if } S \cap T \neq \emptyset \\ 0, & \text{otherwise.} \end{cases}$
Shapley interaction	$I^\xi(S) = \sum_{K \subseteq X} \frac{ X \setminus (S \cup K) ! K \setminus S !}{(n-s+1)!} (-1)^{ S \setminus K } \xi(K)$	$b_T^I(S) = \beta_{ T \cap S }^{ T }$
Banzhaf interaction	$I_B^\xi(S) = \left(\frac{1}{2}\right)^{n-s} \sum_{K \subseteq X} (-1)^{ S \setminus K } \xi(K)$	$b_T^{IB}(S) = \left(\frac{1}{2}\right)^{ T } (-1)^{ T \setminus S }$
Fourier	$F^\xi(S) = \widehat{\xi}(S) = \frac{1}{2^n} \sum_{K \subseteq X} (-1)^{ S \cap K } \xi(K)$	$b_T^F(S) = \chi_T(S) = (-1)^{ S \cap T }$
Walsh	$W^\xi(S) = \frac{1}{2^n} \sum_{K \subseteq X} (-1)^{ S \setminus K } \xi(K)$	$w_T(S) = (-1)^{ T \setminus S }$
Yokote ($T \neq \emptyset$)	$Y^v(S) = \sum_{L \subseteq X} (-1)^{ S \cap L +1} \frac{(n-s-l)!(s+l-1)!}{n!} v(L)$	$v_T(S) = \begin{cases} 1, & \text{if } S \cap T = 1 \\ 0, & \text{otherwise} \end{cases}$

Table A.1 Linear invertible transforms and their associated bases

A.2 Conversion Formulae Between Transforms

We summarize all formulas established in Chap. 2 for passing from one representation of a set function ξ to another. The readers can also consult [178], where all conversion formulae between the Möbius, co-Möbius, interaction and Banzhaf interaction transforms are proved (Tables A.2, A.3, A.4, and A.5).

The superscript $.\xi$ is omitted in m, \check{m} , etc. Cardinality of sets are indicated in corresponding small letters. We recall that $|X| = n$.

	ξ	m	\check{m}
$\xi(A) =$	$\xi(A)$	$\sum_{B \subseteq A} m(B)$	$\sum_{B \subseteq X \setminus A} (-1)^b \check{m}(B)$
$m(A) =$	$\sum_{B \subseteq A} (-1)^{a-b} \xi(B)$	$m(A)$	$\sum_{B \supseteq A} (-1)^{b-a} \check{m}(B)$
$\check{m}(A) =$	$\sum_{B \supseteq X \setminus A} (-1)^{n-b} \xi(B)$	$\sum_{B \supseteq A} m(B)$	$\check{m}(A)$
$I(A) =$	$\sum_{B \subseteq X} \frac{(-1)^{ A \setminus B }}{(n-a+1) \binom{n-a}{ B \setminus A }} \xi(B)$	$\sum_{B \supseteq A} \frac{1}{b-a+1} m(B)$	$\sum_{B \supseteq A} \frac{(-1)^{b-a}}{b-a+1} \check{m}(B)$
$I_B(A) =$	$\left(\frac{1}{2}\right)^{n-a} \sum_{B \subseteq X} (-1)^{ A \setminus B } \xi(B)$	$\sum_{B \supseteq A} \left(\frac{1}{2}\right)^{b-a} m(B)$	$\sum_{B \supseteq A} \left(-\frac{1}{2}\right)^{b-a} \check{m}(B)$

Table A.2 Conversion formulae between $\xi, m, \check{m}, I,$ and I_B

	I	I_B
$\xi(A) =$	$\sum_{D \subseteq X} \beta_{ A \cap D }^d I(D)$	$\sum_{B \subseteq X} \left(\frac{1}{2}\right)^b (-1)^{ B \setminus A } I_B(B)$
$m(A) =$	$\sum_{B \supseteq A} B_{a-b} I(B)$	$\sum_{B \supseteq A} \left(-\frac{1}{2}\right)^{b-a} I_B(B)$
$\check{m}(A) =$	$\sum_{B \supseteq A} (-1)^{b-a} B_{b-a} I(B)$	$\sum_{B \supseteq A} \left(\frac{1}{2}\right)^{b-a} I_B(B)$
$I(A) =$	$I(A)$	$\sum_{B \supseteq A} \frac{1 + (-1)^{b-a}}{(b-a+1)2^{b-a+1}} I_B(B)$
$I_B(A) =$	$\sum_{B \supseteq A} \left(\frac{1}{2^{b-a-1}} - 1\right) B_{b-a} I(B)$	$I_B(A)$

Table A.3 Conversion formulae between $\xi, m, \check{m}, I,$ and I_B (ctd³)

Relations between the Fourier, Banzhaf interaction and Walsh transforms:

$$\widehat{\xi}(A) = \left(\frac{-1}{2}\right)^a I_B^\xi(A) = (-1)^a W(A)$$

	ξ	m	$\widehat{\xi}$
$\xi(A) =$	$\xi(A)$	$\sum_{B \subseteq A} m(B)$	$\sum_{B \subseteq X} (-1)^{ A \cap B } \widehat{\xi}(B)$
$m(A) =$	$\sum_{B \subseteq A} (-1)^{a-b} \xi(B)$	$m(A)$	$(-2)^a \sum_{B \supseteq A} \widehat{\xi}(B)$
$\widehat{\xi}(A) =$	$\frac{1}{2^n} \sum_{B \subseteq X} (-1)^{ A \cap B } \xi(B)$	$(-1)^a \sum_{B \supseteq A} \frac{1}{2^b} m(B)$	$\widehat{\xi}(A)$

Table A.4 Conversion formulae between ξ , m and $\widehat{\xi}$

	v	m	Y
$v(A) =$	$v(A)$	$\sum_{B \subseteq A} m(B)$	$\sum_{B: B \cap A =1} Y(B)$
$m(A) =$	$\sum_{B \subseteq A} (-1)^{a-b} v(B)$	$m(A)$	$a(-1)^{a+1} \sum_{B \supseteq A} Y(B)$
$Y(A) =$	$\sum_{B \subseteq X} (-1)^{ A \cap B +1} \frac{(n-a-b)!(a+b-1)!}{n!} v(B)$	$(-1)^{a+1} \sum_{B \supseteq A} \frac{1}{b} m(B)$	$Y(A)$

Table A.5 Conversion formulae between v , m and Y . These formulae are valid for games only

List of Symbols

\sqsubseteq	Order relation for coverings	126
\sqcap	Intersection of coverings	128
\sqcup	Union of coverings	128
\wedge	Lattice operation : infimum/minimum	3
\vee	Lattice operation : supremum/maximum	3
\otimes	Symmetric maximum	201
\ominus	Symmetric minimum	207
$\bigwedge Q$	Infimum of the poset Q	8
$\bigvee Q$	Supremum of the poset Q	8
$\bigcap Q$	Infimum of the poset Q when $\wedge = \cap$	8
$\bigcup Q$	Supremum of the poset Q when $\vee = \cup$	8
\oplus	Binary addition	96
\oplus	Pseudo-addition	271
\ominus	Pseudo-difference	271
\otimes	Pseudo-multiplication	270
\otimes	Dempster's rule of combination	392
\otimes^*	Nonnormalized rule of combination	394
$*$	Convolution product	97
$*$	Concatenation	328
\succ_{lex}	Lexicographic ordering	331
\succ^*	Quaternary relation	334
\succ_{lmax}	Leximax order	373
\succ_{lmin}	Leximin order	373
\prec, \succ	Covering relation	9
\subset, \supset	Covering relation for sets	9
$\succeq_{\text{SD}}^{\mu}$	Stochastic dominance w.r.t. μ	211
\top	Transposition of matrices and vectors	2

$\langle x, y \rangle$	Inner product of x, y	2
$\downarrow x$	Principal ideal of x	10
$\downarrow Q$	Downset generated by Q	10
$\uparrow x$	Principal filter of x	10
$\uparrow Q$	Upset generated by Q	10
∇f	Gradient of f	19
$\nabla(A)$	Potential certainty of A	416
$\nabla_k \xi$	Difference function of Choquet	36
∂f	Superdifferential of f	19
$\int \cdot d\mu$	Choquet integral w.r.t. μ	192
$\int_A \cdot d\mu$	Choquet integral w.r.t. μ on A	196
$\int_{\mathcal{F}} \cdot d\mu$	Extended Choquet integral w.r.t. μ	272
$\int \cdot d\mu$	Symmetric Choquet integral w.r.t. μ	197
$\int \cdot d\mu$	Sugeno integral w.r.t. μ	193
$\int \cdot d\mu$	Symmetric Sugeno integral w.r.t. μ	200
$\int^{\text{Sh}} \cdot d\mu$	Shilkret integral	259
$\int^{\text{cav}} \cdot d\mu$	Concave integral	260
$\int_{\mathcal{D}} \cdot d\mu$	Decomposition integral	265
$[0, 1]_{\sigma}^n$	Canonical simplex of the unit hypercube	116
$\mathbf{0}$	Zero vector	2
\mathbb{O}	Neutral level	339
$\mathbf{1}$	Vector whose every component is one	2
1_A	Characteristic function of a set A	2
\mathbb{I}	Satisfactory level or upper bound	340
$-\mathbb{I}$	Unsatisfactory level or lower bound	340
β_k^l	Coefficient	66
γ	Bernoulli generator function	62
δ	Dirac function	22
δ	Guaranteed possibility distribution	416
δ_A	Dirac game centered at A	75
δ_{x_0}	Dirac measure centered at x_0	27
ζ	Zeta generator function	62
$\lambda(\cdot, \cdot)$	Sharing system	182
μ	Capacity	27
μ^*, μ_*	Upper and lower probabilities	379
$\mu(x, y)$	Möbius function	51
μ_{\max}	Greatest normalized capacity	42
μ_{\min}	Smallest normalized capacity	42
$\mu_S^{(1)}$	Subset coverage function for random set S	388
$\mu_S^{(2)}$	Superset coverage function for random set S	388
$\mu_S^{(3)}$	Incidence function for random set S	388

$\mu_S^{(4)}$	Complement incidence function for random set S	388
μ_B	General conditional capacity given B	400
μ_B^{Ba}	Bayes conditional capacity given B	406
μ_B^{DS}	Dempster-Shafer conditional capacity given B	406
ξ	Set function	26
$\widehat{\xi}$	Fourier transform of set function ξ	97
$\bar{\xi}$	Conjugate of set function ξ	26
π	Possibility distribution	43
$\pi\text{-core}(\mu)$	Possibilistic core of μ	423
ρ	Rank function of a matroid	31
v_T	Vector of the Yokote basis	120
ϕ^{B}	Banzhaf value	60
ϕ^{Sh}	Shapley value	60
ϕ^α	Selecter value	181
ϕ^λ	Sharing value	182
$\widehat{\varphi}$	Cardinal representation of cardinality function φ	63
φ^{*-1}	Inverse of cardinality function φ	62
χ_S	Parity function	96
$\Gamma(A, B)$	Bernoulli operator	62
Δ	Symmetric difference of sets	2
$\Delta(A)$	Guaranteed possibility of A	415
$\Delta_i \xi$	Derivative of set function ξ w.r.t. i	32
$\Delta_K \xi$	Derivative of set function ξ w.r.t. K	33
$\Delta_i f$	Derivative of pseudo-Boolean function f w.r.t. i	91
$\Delta_A f$	Derivative of pseudo-Boolean function f w.r.t. A	91
$\Delta_K F$	Total variation of function F w.r.t. K	361
$\Delta(A, B)$	Kronecker's delta	61
$\Lambda(N)$	Set of sharing systems on N	182
Π	Possibility measure	43
$\Pi(X)$	Set of all partitions of X	9
b	Bicapacity	352
b_T^I	Vector of the basis associated to the interaction transform	119
b_T^{B}	Vector of the basis associated to the Banzhaf interaction transform	119
cone	Conic hull of a set of points	13
conv	Convex hull of a set of points	13
core (v)	Core of game v	146
core [*] (v)	Anticore of game v	147
core ^b (v)	Bounded core of game v	172
core _{\mathcal{N}} (v)	Bounded face of the core of game v	170

$\text{dom } f$	Domain of function f	1
$\text{ess inf}_{\mu} f$	Essential infimum of f w.r.t. μ	191
$\text{ess sup}_{\mu} f$	Essential supremum of f w.r.t. μ	191
ext	Set of extreme points of a convex set	15
$\ f\ $	Norm of f	93
\widetilde{f}	Equimeasurable rearrangement of f	258
f^{Lo}	Lovász extension of pseudo-Boolean function f	116
f^{Ow}	Owen extension of pseudo-Boolean function f	109
\widehat{f}	Fourier transform of pseudo-Boolean function f	97
$f _Y$	Restriction of function f to Y	2
f^+, f^-	Positive and negative parts of function f	196
f_{EG}	Compound act	282
g	Abelian group of generator functions	62
h_C	Support function of convex set C	19
$h(P, \preceq)$	Height of poset (P, \preceq)	9
$h(x)$	Height of element x in a poset	9
ker	Kernel of a linear mapping	123
m	Measure	27
m	Mass distribution	380
m_*	Ordinal Möbius transform	238
m^{ξ}	Möbius transform of ξ	49
m_X	Vacuous mass distribution	384
$m_{B,\alpha}$	Simple mass distribution	384
\widetilde{m}^{ξ}	Co-Möbius transform of ξ	58
m_c	Counting measure	27
mc (v)	Monotone cover of game v	33
med	Median	206
$[n]$	Index set defined by $\{1, \dots, n\}$	2
q	Commonality function	381
ran f	Range of function f	1
s	Additive generator of t-conorm S	45
$s_{\mathbb{L}}$	Additive generator of the Łukasiewicz t-conorm	45
$s_{\mathbb{P}}$	Additive generator of the probabilistic sum	45
s_{λ}^{SW}	Additive generator of the Sugeno-Weber t-conorms	47
sel (v)	Selectope of game v	181
sign	Signum function	2
supp (f)	Support of function f	1
tbc (v)	Totally balanced cover of game v	175
u_A	Unanimity game centered on A	43

\check{u}_T	Vector of the basis associated to the co-Möbius transform	118
v	Game	26
v^+	Positive part of game v	81
v^-	Negative part of game v	81
$ v $	Absolute value of game v	81
$\ v\ _c$	Composition norm of game v	81
\bar{v}	Conjugate of game v	26
v_*	Lower envelope of game v	174
w_T	Walsh function	93
$\{x_n\}$	Countable family x_1, x_2, \dots	2
$x _Y$	Restriction of vector x to coordinates in Y	2
x_Y	Restriction of vector x to coordinates in Y	2
x_{-Y}	Restriction of vector x to coordinates not in Y	2
$x^{\sigma, v}$	Marginal vector	154
A/\sim	Quotient set of A	8
A^c	Complement of set A	2
$A^\uparrow_\sigma(\cdot)$	Upper level set	208
$A^\downarrow_\tau(\cdot)$	Lower level set	208
$A(v)$	Set of acceptable vectors of v	174
$\underline{A}(v)$	Set of minimal elements of $A(v)$	174
B_n	Bernoulli numbers	6
$B_n(x)$	Bernoulli polynomials	6
$B(\mathcal{F})$	Set of bounded \mathcal{F} -measurable functions	191
$B^+(\mathcal{F})$	Set of nonnegative bounded \mathcal{F} -measurable functions	191
Bel	Belief measure, belief function	44
Bel*	Normalized belief function	385
\emptyset		
Bel	Modified belief function	390
BetP ^m	Pignistic probability distribution	412
$C(P)$	Recession cone of polyhedron P	14
$C(A, B)$	Co-Möbius operator	64
CE(f)	Certainty equivalent of act f	303
CEU(f)	Choquet expected utility of act f	310
EU(p)	Expected utility of lottery p	287
EV(f)	Expected value of act f	303
F^ξ	Fourier transform	119
$G_{f, \mu}$	Decumulative distribution function of f w.r.t. μ	191
I^ξ	Interaction transform of ξ	58
I_{ij}^{Sh}	Shapley interaction index for i, j	359
I_B^ξ	Banzhaf interaction transform of ξ	59
I_{ij}^{B}	Banzhaf interaction index for i, j	359

$I_K(F)$	Interaction index of K on function F	361
$I(v)$	Set of imputations of game v	179
Id	Identity function	1
M_3	Lattice M_3	11
N_5	Lattice N_5	11
$M(n)$	Dedekind number	42
MEU(f)	Maxmin expected utility of act f	315
Nec	Necessity measure	43
OS _{k}	k th ordered statistic	247
OWA _{w}	Ordered weighted arithmetic mean	247
OWMax _{w}	Ordered weighted maximum	252
OWMin _{w}	Ordered weighted minimum	252
P^∂	Dual poset of P	8
P _{k}	Projection on k th coordinate	247
Pl	Plausibility measure, plausibility function	44
PT(p)	Prospect theory model for lottery p	301
RDU(p)	Rank dependent utility for lottery p	296
S	t-conorm	44
SL	Łukasiewicz t-conorm	44
Sp	Probabilistic sum (t-conorm)	44
S _{λ} ^{SW}	Family of Sugeno-Weber t-conorms	46
SugEU(f)	Sugeno expected utility of act f	321
T^*, T_*	Upper and lower approximation of set T	379
\overline{U}^ξ	Transform associates to conjugate unanimity games	118
Var[f]	Variance of f	97
W^ξ	Walsh transform	120
WAM _{w}	Weighted arithmetic mean	247
Web (v)	Weber set of game v	154
WMax _{w}	Weighted maximum	252
WMin _{w}	Weighted minimum	252
Y^ξ	Yokote transform	120
$Z(A, B)$	Zeta operator	61
\mathcal{B}	Balanced collection	148
$\mathcal{B}(X)$	Set of belief functions on X	44
$\mathcal{BV}(\mathcal{F})$	Set of games of bounded variation	134
$\mathcal{C}(P)$	Chain polytope of P	88
\mathcal{C}_B	Class of superset coverages of B	387
\mathcal{D}_B	Class of subset coverages of B	387
\mathcal{E}_B	Class of incidences relative to B	387
\mathcal{F}	Set system	130
\mathcal{G}	Group of triangular matrices with diagonal 1	61

$\mathcal{G}(X)$	Set of games on X	26
$\mathcal{G}(X, \mathcal{F})$	Set of games on set system \mathcal{F}	130
$\mathcal{G}_+(X)$	Set of totally monotone nonnegative games on X	79
$\mathcal{G}_\diamond(X)$	Set of zero-normalized supermodular games on X	78
$\mathcal{G}^k(X)$	Set of k -additive games on X	73
$\mathcal{G}^{\leq k}(X)$	Set of at most k -additive games on X	73
$\mathcal{I}(A, B)$	Interaction operator	68
$\mathcal{I}_B(A, B)$	Banzhaf interaction operator	71
$\mathcal{J}(L)$	Set of join-irreducible elements of L	11
$\mathcal{L}(f)$	Laplace transform of f	22
$\mathcal{M}(L)$	Set of meet-irreducible elements of L	11
$\mathcal{M}(v)$	Möbius covering of game v	125
$\mathcal{M}(X)$	Set of measures on X	27
$\mathcal{MG}(X)$	Set of capacities on X	28
$\mathcal{MG}^k(X)$	Set of k -additive capacities on X	73
$\mathcal{MG}^{\leq k}(X)$	Set of at most k -additive capacities on X	73
$\mathcal{MG}_0(X)$	Set of normalized capacities on X	28
\mathcal{N}	Normal collection	169
$\mathcal{O}(P, \preceq)$	Set of downsets of the poset (P, \preceq)	10
$\mathcal{O}(P)$	Order polytope of P	87
$\mathcal{P}(n)$	Set of Owen extension of pseudo-Boolean functions	109
$\mathcal{PB}(n)$	Set of pseudo-Boolean functions on $\{0, 1\}^n$	91
$\mathcal{PB}^{\leq k}(n)$	Set of pseudo-Boolean functions of degree at most k	101
$\mathcal{WLP}(L; n)$	Class of weighted lattice polynomial functions	368
\mathbb{C}	Set of complex numbers	1
$\mathbb{E}[f]$	Expected value of f	97
\mathbb{N}	Set of positive integers	1
\mathbb{N}_0	Set of nonnegative integers	1
\mathbb{Q}	Set of rational numbers	1
\mathbb{R}	Set of real numbers	1
\mathbb{Z}	Set of integers	1
$\mathcal{C}(X)$	Set of coverings of X	125
$\mathcal{C}^\circ(X)$	Set of irreducible coverings of X	127
\mathcal{D}	Set of collections for the decomposition integral	265
$\mathcal{D}^{\text{chain}}$	Set of chains for the decomposition integral	266
$\mathcal{D}^{\text{sing}}$	Set of singletons for the decomposition integral	266
$\mathcal{IEC}(v, X)$	Set of inclusion-exclusion coverings	125
$\mathcal{IEC}^\circ(v, X)$	Set of irreducible inclusion-exclusion coverings	128
$\mathcal{S}(N)$	Set of permutations on N	2

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